



# The Realized Results of LED Streetlights: Seizing the Opportunity

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## EXECUTIVE SUMMARY

Streetlighting can be one of the largest electricity users, and therefore costs, of a municipality. It also contributes to approximately 5-6% of total global CO<sub>2</sub> emissions. Over the past decade, LED technology has emerged as the primary choice for streetlight luminaires, promoted by: expected 40-50% energy savings; reduced maintenance and operation costs; improved safety and security; and reduced light pollution and light trespass.

This document provides information on how light-emitting diode (LED) streetlighting has evolved, specifically in Canada, lessons learned from early adopters and the realized results; it is intended to help accelerate adoption of LEDs with those who have not yet converted.

Early North American adopters that have become leaders in LED installations include: City of Edmonton; City of Hamilton; Manitoba Hydro; City of Mississauga; New Brunswick Power; Province of Nova Scotia; City of Los Angeles; and City of Seattle. Based on results from these initial installations and others, LED technology has improved in the areas of light output and distribution, thermal management, surge protection, correlated colour temperature (CCT), interoperability and glare mitigation. Coupled with advancements in energy efficiency, lower product pricing and suitability to adaptive and intelligent controls, converting incumbent streetlights to LED technology presents the greatest potential benefits for communities than ever before.

This report also evaluates realized results of specific LED streetlight projects regarding energy savings, maintenance savings, carbon emissions reductions and quality of service. For all projects investigated, results have either met or exceeded the design expectations in all categories. True energy savings range from 30-65%, depending on luminaire and roadway type. In some cases, it is too early to determine actual maintenance savings, however, after only four years, New Brunswick Power is achieving a 65% reduction in annual maintenance, ahead of initial targets. Reductions in carbon emissions were also case specific and dependent on how energy is generated. The City of Edmonton's conversion of 30,000 streetlights to LED is reporting annual carbon savings of 5,500 tonnes. Quality of service is more difficult to monitor as it relates to the subjective opinion of users. In four cities where residents were surveyed on their perception of LED technology, over 50% of responses in each case were positive.

Based on the realized results evaluated and public response, this report discusses six key lessons learned. Firstly, a streetlighting inventory that is up-to-date and stored in a common digital database will significantly improve the efficiency and costs of an LED conversion project. Secondly, when planning a streetlight conversion, lighting asset managers should take advantage of the opportunity for a lighting redesign and ensure there are no areas overlit. Thirdly, brighter and whiter light does not necessarily increase visibility, meaning LEDs with lower correlated colour temperature may be considered. Fourthly, it is important to engage the public early on to address any concerns they may have before full-scale implementation. Fifthly, potential increase in electricity rates should be considered in the business case. Lastly, integrating adaptive controls with LED streetlights will provide additional energy and maintenance benefits and future-proof systems for emerging smart city applications.

Finally, LightSavers reviews research on the potential and environmental effects of light at night, specifically that with a higher (or bluer) CCT. There is general agreement across the literature reviewed that, with proper design, high intensity discharge streetlights should be replaced with LED technology to achieve the environmental, social and cost saving benefits. Existing research does not provide substantial evidence to confirm exposure to LED streetlights causes any significant health impacts and, furthermore, humans are likely exposed to more blue light within their homes than on the street.

Early adopters have provided evidence-based reasoning for LED streetlight installations by establishing that lighting standards can be met while intended benefits are achieved and additional opportunities are presented for newer technologies like networked intelligent controls.

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# 1. INTRODUCTION

## 1.1 PURPOSE

This document is intended for lighting asset managers, manufacturers and end-users to provide information on how light-emitting diode (LED) streetlighting has evolved, specifically in Canada, lessons learned from early adopters and the realized results. The information presented is intended to help accelerate the adoption of energy efficient streetlighting by those who have not yet converted their incumbent luminaires.

Typically, streetlighting is one the largest energy consumers, and therefore greatest costs, of a municipality. Globally, electricity used for lighting is estimated to produce 5-6% of the total CO<sub>2</sub> emissions<sup>1</sup>. As a technology that not only reduces energy use and associated carbon emissions, but also saves money and provides additional community benefits, LED luminaires are now the industry standard for new streetlights installations. With the expected, and now, observed impacts of climate change on the environment and humans, the need for communities to invest in low-to-zero carbon strategies has never been greater. However, adoption has been slower than expected both in Canada and globally. This resource presents the evolution of LED streetlights and realized results of existing implementations to support a full switch to LED luminaires.

## 1.2 LED STREETLIGHT HISTORY

LED streetlights have evolved as an alternative to the incumbent high intensity discharge (HID) lamps, most commonly being high-pressure sodium (HPS) or metal halide (MH). In the early years of LED streetlight production (approximately 2004-2008), the technology had high initial capital costs and was not consistently observed to meet standard illumination requirements, such as the Illuminating Engineering Society (IES) RP-8 guidelines. Between 2009 and 2011, costs began to decrease and light distribution improved to meet standards. Furthermore, there were potential significant gains to converting HID streetlights to LED, as described below:

- **Energy and CO<sub>2</sub> savings:** LEDs provide greater efficacy (lumen output per watt) than HID lamps that reduces energy consumption by 40-70% and has associated carbon emissions reductions;
- **Reduced maintenance requirements:** The operational lifespan of LED luminaires is significantly longer than HID lamps, along with more reliable technology resulting in fewer failures;
- **Improved safety and security:** LEDs are claimed to provide better colour rendition and illumination uniformity to improve object detection and enhance surveillance, as well as benefit traffic safety; and
- **Reduce light pollution and light trespass:** The directionality of LED lighting is should reduce sky glow and produce negligible obtrusive light, adding to improved aesthetics by correctly lighting targeted areas.

More information on the proposed benefits of LED streetlights is discussed in *LED Streetlight Scale-up: A LightSavers Guide*<sup>2</sup>. The potential advantages of LED technology, along with reduced costs, led to initial pilot projects, including the two-year global trials LightSavers conducted in 2009-2012 with The Climate Group and The Atmospheric Fund. This pilot program analysed performance results of 14 outdoor LED trials 29 different luminaires. Results demonstrated LED lighting is a reliable technology, with average energy reduction between 40 and 70 percent.<sup>3</sup>

## 1.3 LED STREETLIGHT SCALE-UPS

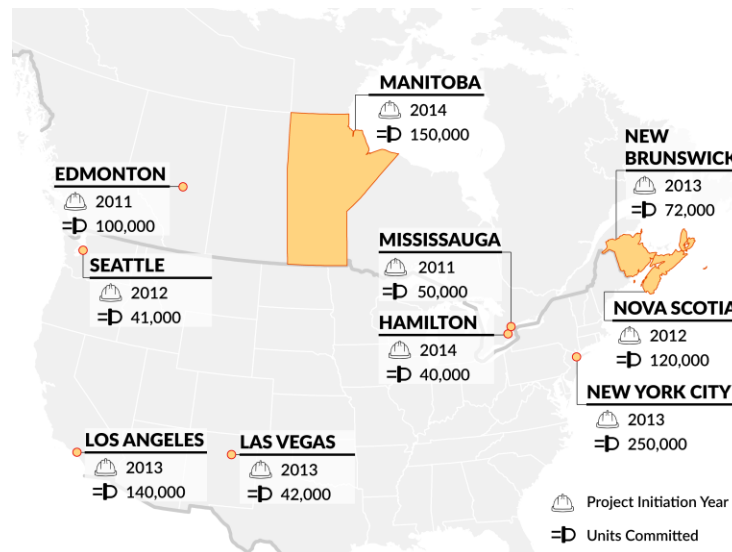
Since 2008, the streetlight market has shifted globally and, in Canada, LED luminaires are typically the first choice for new installations. However, full-scale retrofits of existing streetlights are still not widespread across Canada. LightSavers estimates that over 30% of Canadian streetlights are converted or committed to be converted to LED. Below are examples of Canadian provinces, municipalities or utilities have become leaders in LED streetlight scale-

<sup>1</sup> [http://www.se4all.org/energyefficiencyplatform\\_lighting](http://www.se4all.org/energyefficiencyplatform_lighting)

<sup>2</sup> <http://www.lightsavers.ca/resources/>

<sup>3</sup> <http://static1.squarespace.com/static/546bbd2ae4b077803c592197/t/552ea432e4b0e4e51050bceb/1429120050403/Meta-analysis.pdf>

up programs by realizing the opportunities of LED technology early on and/or are implementing widespread conversions.



### a) Edmonton, AB [100,000 Streetlights]

The City of Edmonton was one of the first Canadian municipalities to conduct an LED streetlight pilot, installing trial LEDs in 2007. The early test demonstrated unfavourable results for light levels, light distribution and equipment failures. However, building on lessons learned from the first, Edmonton implemented a second pilot in 2009, comparing five LED manufacturers with each other and the existing HPS luminaires. The LEDs showed favourable results and met or exceeded all lighting requirements measured. Following these results, Edmonton has consistently been scaling-up their 100,000 streetlight to LEDs since 2011, with approximately 30,000 completed to date.<sup>4</sup>

### b) Hamilton, ON [40,000 Streetlights]

Through the LightSavers program, the City of Hamilton installed a pilot project in 2009 where four HPS streetlight luminaires were switched to LED. Throughout the trial, the LEDs achieved North American lighting standards with 50% less energy, however, they did not have sufficient surge protection. Hamilton conducted two more trials, and is currently implementing a full-scale conversion to LED, following a 10,000-luminaire retrofit completed in 2015.<sup>5</sup>

### c) Manitoba Hydro [150,000 Streetlights]

After installing initial LED streetlight pilots in 2013, Manitoba Hydro launched one of Canada’s most aggressive and ambitious conversion programs in June 2014. Having exclusive or shared ownership of almost all Manitoba’s streetlights, Manitoba Hydro was able to commit to convert 150,000 to LED luminaires by 2021. As of November 2016, 36,000 LEDs have been installed.<sup>6</sup>

<sup>4</sup> <https://static1.squarespace.com/static/546bbd2ae4b077803c592197/v/55195797e4b0ef9291b864fc/1427724183174/Edmonton+Case+Study.pdf>

<sup>5</sup> <http://taf.ca/hamilton-pilot-project-illuminates-challenges-opportunities-with-led-street-lighting/>

<sup>6</sup> [https://www.hydro.mb.ca/your\\_business/roadway\\_lighting/index.shtml](https://www.hydro.mb.ca/your_business/roadway_lighting/index.shtml)

#### d) Mississauga, ON [50,000 Streetlights]

The City of Mississauga is known as one of the first Canadian municipalities to implement a city-wide LED streetlight scale-up program. In 2004, Mississauga retrofitted all traffic signals to LED and, in 2009, launched a yearlong streetlight pilot project to trial LED and induction luminaires. Evaluation conducted by a third party confirmed LED luminaires met illumination and uniformity requirements while reducing both energy requirements and maintenance costs by more than half that of the HPS incumbent lamps. The LED test lights were also equipped with adaptive controls to regulate light output providing additional energy savings and extending luminaire operational life. In 2011, Council approved a full-scale conversion of the City's 50,000 streetlights to LEDs with adaptive controls that was completed in 2015.

#### e) New Brunswick Power [72,000 Streetlights]

The New Brunswick Power (NB Power) utility has committed to rely less on GHG fuels. NB Power considers LED streetlighting a major opportunity for energy savings and lowered GHG emissions. Throughout 2008-2009, the utility began piloting over 400 LED luminaires of varying manufacturers and specifications. NB Power also prepared for a successful streetlight conversion by completing a digital inventory of all streetlights, mapping exact pole locations using geographic information systems (GIS). By 2013, NB Power had a strong enough business case based on the pilot project to commit to retrofit the province's 72,000 streetlights to LED. As of 2016, over 40,000 streetlights have been replaced and the project is ahead of schedule.

#### f) Nova Scotia [120,000 Streetlights]

In 2012, the Province of Nova Scotia became the first jurisdiction in North America to mandate LED streetlighting in an amendment to the Energy Efficient Appliances Act. The province's amended legislation deemed the incumbent HPS streetlights as inefficient technology and requires all 120,000 streetlights to be replaced. When the mandate was invoked, Nova Scotia Power owned and operated 90% of the province's streetlights. The utility was given until December 31, 2019 to complete a full-scale conversion, while municipalities have until December 31, 2022 to complete their LED retrofits.<sup>7</sup>

The Halifax Regional Municipality, who purchased its 43,000 streetlights from Nova Scotia Power in August 2014, began converting all streetlights to LED in 2015 and is scheduled to be complete by the end of 2017.<sup>8</sup>

America has also seen significant adoption of LED streetlights in many of its major municipalities. Los Angeles was one of the earliest full-scale implementations of LEDs in North America. In 2013, LA implemented, at that time, the world's largest LED streetlight retrofit program for 140,000 lights. Also in that year, Las Vegas converted 42,000 streetlights to LED<sup>9</sup> and New York City committed to replacing its 250,000 units<sup>10</sup>. Even earlier, Seattle had converted 21,000 of its 41,000 streetlights to LED by 2012 and was already saving \$1.2 million in energy costs.<sup>11</sup> The U.S. Department of Energy (DOE) estimates that by 2035, LED luminaires will comprise 86% of lighting installations in the United States.<sup>12</sup> However, The Climate Group believes it is possible and needed for all streetlights to be LED by 2025.<sup>13</sup>

<sup>7</sup> <http://www.ledsmagazine.com/articles/2012/09/nova-scotia-mandates-all-led-street-lights.html>

<sup>8</sup> <http://www.halifax.ca/traffic/LED/>

<sup>9</sup> <http://www.forbes.com/sites/justingerdes/2013/07/31/los-angeles-completes-worlds-largest-led-street-light-retrofit/#382413f04b54>

<sup>10</sup> <https://singularityhub.com/2013/11/10/new-york-city-to-replace-250000-street-lights-with-leds-by-2017/>

<sup>11</sup> <https://www.bostonglobe.com/opinion/2012/08/02/podiumstreetlight/9qVaAubIxU0j27bcavREaK/story.html>

<sup>12</sup> <http://www.energy.gov/eere/ssl/ssl-forecast-report>

<sup>13</sup> <https://www.theclimategroup.org/project/led-scale>

## 2. THE EVOLUTION OF LEDS

### 2.1 LESSONS FROM EARLY INSTALLATIONS

The major early trials of LED streetlights undertaken between 2007 and 2009, with some experiencing significant technical issues of first generation luminaires, including:

- **Light output and distribution:** early LEDs did not consistently meet North American lighting requirements, or in some cases, only met requirements if pole spacing was adjusted, adding to the already high capital costs<sup>14</sup>;
- **Thermal management:** elevated failure rates of LEDs were most commonly caused by poor thermal management, with the higher power of LEDs compared to HID lamps causing an increased thermal load and more heat to dissipate; some first generation fixtures were equipped with insufficient heat sinks which resulted in LED drivers failing prematurely<sup>15</sup>;
- **Surge protection:** initial testing of LEDs showed that their driving electronics are more vulnerable to power surges than typical HID lamps; in some trials, LEDs failed in significant power surge events, demonstrating the importance of effective surge protection for this new technology<sup>16</sup>;
- **Correlated Colour Temperature (CCT):** very early installations of LEDs commonly used luminaires with cool-white colour temperatures (5000-6500K CCT) that appear much whiter and brighter than the legacy HPS lamps with approximate CCTs of 2700K; in some cases, this increase in CCT has been received poorly by the public, encouraged by misinformation by the media, and many new installations now use 4000K or lower LEDs.

LED streetlights developed since the early trials can easily exceed lighting requirements and surpass performance metrics of incumbent HID lamps, while using significantly less energy.

With the technical advancements informed by the initial trial results, LEDs became a viable option for municipal roadway lighting in terms of illumination requirements and luminaire performance. This paradigm shift in streetlighting presented an opportunity for streetlighting to go beyond just meeting a minimum illumination requirement. Municipalities now identify the best luminaires in terms of light quality, safety and security, environmental protection and future-proofing. To realize these opportunities, decision-makers considering LED streetlight installations should stay up to date with current lighting standards, LED capabilities, industry recommendations and public perception.

### 2.2 LED TECHNOLOGY ADVANCEMENTS

Changes to LED performance have come from lessons learned through trials, general technological advances and greater research into the effects of light at night. Some of the important areas where LEDs have improved include:

<sup>14</sup> <http://www.lrc.rpi.edu/programs/NLPIP/PDF/VIEW/SRStreetlights.pdf>

<sup>15</sup> <http://www.ledsmagazine.com/articles/print/volume-4/issue-8/features/driving-led-lamps-some-simple-design-guidelines.html>

<sup>16</sup> <http://taf.ca/hamilton-pilot-project-illuminates-challenges-opportunities-with-led-street-lighting/>





- **Energy efficiency:** as shown in the graph below, improvements in luminaire efficacy (lumens per watt), wavelength composition and light directionality have significantly increased the energy savings potential of LED and it is now common to expect a minimum energy use reduction of 50% when switching from HID to LED.
- **Operational lifespan:** LED streetlight specifiers can now expect service lives upwards of 20 years (or lumen maintenance of 100,000 hours) and require manufacturer warranties of at least 10 years. Not only is this almost seven times the expected life of HPS lamps, it is double what early LEDs were promising.
- **Product costs:** since LEDs have entered the market, product pricing has steadily decreased to current costs now being lower than some HID lamps<sup>17</sup>;
- **Correlated colour temperature (CCT):** the CCT of early LED luminaires was typically 5000K or above, containing more blue wavelengths than the typical 2700K HPS lamps and more closely resembling sunlight (approximately 5600K). These higher CCT values were initially preferred because of the significant increase in energy efficiency with increase in blue light content and for the expected benefits to perceived security. However, the industry standard for CCT has since decreased, with the International Dark-Sky Association (IDA) now recommending a maximum CCT of 3000K, and several communities requesting warmer light output. Due to energy efficiency improvements, 3000K LEDs are now available with less than 5% decrease in efficacy compared to 4000K luminaires<sup>18</sup>.
- **Interoperability and modularity:** although many early luminaires were built with manufacturer-specific parts and connectors, promoting interoperability and modularity of LED luminaire components helps municipalities future-proof their systems and is becoming more common across manufacturers<sup>19</sup>.
- **Glare mitigation:** in some early LED installations, the new luminaires were appearing to have greater glare than incumbent fixtures. Past studies have shown that, under the same light levels, blue light is perceived brighter by the human eye than warmer colours and is likely the reason first generation LEDs with higher blue light content have performed poorly in glare tests<sup>20</sup>. In response, some manufacturers have developed anti-glare shields that can be retrofitted in fixtures post luminaire installation.
- **Lighting controls:** unlike HID luminaires, LEDs are well suited to adaptive controls due to their dimming capabilities, instant ON/OFF functionality and the expected negligible impact on their service life of frequent ON/OFF. Adaptive controls adjust luminaire output to meet actual lighting requirements, thereby

<sup>17</sup> <https://www.yukonenergy.ca/news/media-releases/yukon-energy-begins-the-switch-to-led-streetlights-throughout-its-service-area>

<sup>18</sup> <http://agi32.com/blog/2015/07/07/color-temperature-and-outdoor-lighting/>

<sup>19</sup> <https://static1.squarespace.com/static/56cdd5262cd94f3e9cfd8e/t/57e035d6e4fcb599e09c8bc3/1474311644569/2.LS.LEDProGuide-v2.150811.pdf>

<sup>20</sup> [http://www.osa.org/en-us/about\\_osa/newsroom/news\\_releases/2014/improving\\_driver\\_safety\\_how\\_to\\_prevent\\_streetlight/](http://www.osa.org/en-us/about_osa/newsroom/news_releases/2014/improving_driver_safety_how_to_prevent_streetlight/)

increasing energy savings and extending a luminaire's life.<sup>21</sup> Dimming by controls can also help mitigate glare issues by reducing light output in conditions that may increase glare, such as wet roads. Networked, intelligent controls present opportunities for smart city initiatives using two-way communication of sensor data. Initially, many lighting asset managers were deterred by the additional capital cost of controls, however most LED streetlight systems in Canada are, at minimum, future-proofing by specifying LED luminaires with dimmable drivers and sufficient pins for controls and power.

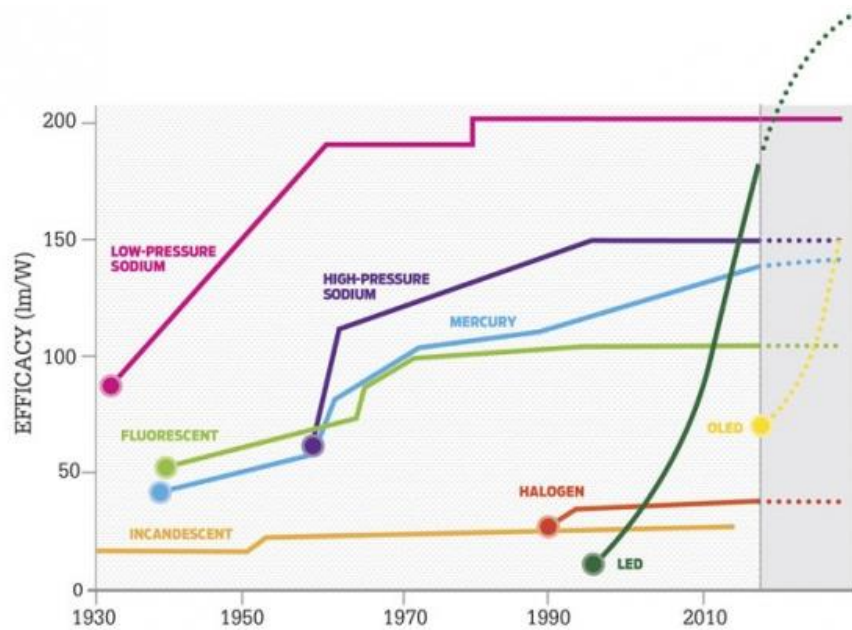


Figure 1: Efficacy trends of common streetlight luminaires across the years<sup>22</sup>

For more information on recommended LED specifications, refer to LightSavers' *Model Technical Specifications for Procurement of LEDs in Canada Version 2.0*<sup>23</sup>.

<sup>21</sup> <https://static1.squarespace.com/static/56cddde5262cd94f3e9cfff8e/t/57b5cca41b631bc0993745a7/1471532197587/LSIV%2B2-3%2BControlPrimer.Final.For%2Bwebsite.pdf>

<sup>22</sup> <http://luxreview.com/article/2015/07/7-graphs-that-tell-you-everything-you-need-to-know-about-lighting>

<sup>23</sup> <https://static1.squarespace.com/static/56cddde5262cd94f3e9cfff8e/t/57e035d6e4fcb599e09c8bc3/1474311644569/2.LS.LEDProGuide-v2.150811.pdf>

## 3. REALIZED RESULTS

Although LED products continue to evolve (getting lighter, more efficient and less expensive), technology improvements are occurring in smaller increments and most existing installations are realizing the expected energy and cost savings.

### 3.1 GLOBAL TRIALS

Since 2012, LED streetlight conversions have typically been showing favourable results for energy and cost savings. Those projects that have not achieved effective economic savings often incurred significant initial costs from requiring modifications to pole spacing<sup>24,25</sup>. However, as discussed, LED technology quickly improved light output and uniformity to meet lighting requirements using existing poles.

A survey of 100 American jurisdictions that had implemented LED streetlights found positive results regarding both cost savings and the public response. The survey found most residents preferred LED illumination over legacy lighting, law enforcement perceived safety improvements and governments realized significant economic benefits. A 2016 follow-up assessment of more than 1,000 LED streetlight projects from over 90 countries found that, with the decreasing capital costs and improved light quality, benefits have only increased.<sup>26</sup>

As discussed, the 2012 LightSavers study evaluated 12 LED installations across seven cities worldwide. The scope included 29 different LED luminaires and adaptive controls used in indoor and outdoor parking, pedestrian pathways, single streets and expressways. Over 70% of the products achieved at least 50% energy savings and exceeded manufacturers' initial indications. Furthermore, the failure rate across all luminaires tested was 1.8% over 4,000 to 6,000 hours, significantly lower than the typical 10% failure of HID lamps. Trials where LEDs were coupled with adaptive controls saw, at minimum, an additional 20% savings. Five of the trials also surveyed public opinion and, in all, found the majority of pedestrians and drivers agreed visibility had improved. LightSavers concluded that LED luminaires had reached technological maturity and that performance concerns should not be a barrier to large-scale adoption.<sup>27</sup>

LightSavers is now analyzing full-scale LED conversion programs to evaluate how realized results are comparing to expectations based on the successful trials, with our initial findings summarized in this report.

### 3.2 DIRECT COST SAVINGS

Reductions in energy and maintenance requirements correspond to direct cost savings, this data is often the most comprehensive data available on the benefits of LED streetlights. LightSavers reviewed realized results of eight full-scale LED conversion projects, each implemented in a different North American jurisdiction with 25% or more of the installation completed at least a year ago.

#### a) Energy Savings

All the projects are meeting expectations in terms of energy savings. The lowest savings is about 30% and the highest over 60% (see Table 1 below).

<sup>24</sup> <http://iet.jrc.ec.europa.eu/energyefficiency/sites/energyefficiency/files/led-test-cases-report.pdf>

<sup>25</sup> <http://www.lrc.rpi.edu/nlpip/publicationDetails.asp?id=927&ttype=1>

<sup>26</sup> <http://www.northeast-group.com/reports/Brochure-Global%20LED%20and%20Smart%20Street%20Lighting%20Market%20Forecast%202016-2026%20-%20Northeast%20Group.pdf>

<sup>27</sup> [https://www.theclimategroup.org/sites/default/files/archive/files/LED-Report-Full-FINAL-low-res\(1\).pdf](https://www.theclimategroup.org/sites/default/files/archive/files/LED-Report-Full-FINAL-low-res(1).pdf)

Table 1: Realized energy savings of LED streetlight scale-up programs in North America

Jurisdiction	LED Luminaires Installed to Date (% of total planned)	True Energy Savings*
City of Barrie, CA	10,500 (100%)	60%
City of Edmonton, CA	30,000 (30%)	40% (5% higher than estimated)
City of Hamilton, CA	10,000 (25%)	57% (7% higher than estimated)
City of Las Vegas, US	42,000 (100%)	30-65%
City of Los Angeles, US	140,000 (100%)	63% (23% higher than estimated)
City of Mississauga, CA	50,000 (100%)	65% (10% higher than estimated)
Manitoba Hydro, CA	37,000 (25%)	40-60%
New Brunswick Power, CA	65,000 (90%)	60% (10% higher than estimated)

\*Does not directly correlate with cost savings and varies across cities based on project specific conditions including: date of installation and roadway type illuminated

Some results presented are still preliminary based on the streetlights that have been converted to date and not the total planned conversions. Only two of the eight LED projects are experiencing energy savings less than 60 percent. Furthermore, Manitoba Hydro has reported that the LEDs tendered for the remaining luminaire conversions have improved specifications and are expected to reduce energy use by a minimum of 50 percent. Moreover, any variances from expected savings are demonstrated increases. Based on these results, late adopters of LED streetlights should expect 60% in energy savings compared to HID lamps, which will, along with the decreased products costs, help support a strong business case for making the switch.

### b) Maintenance Savings

Direct cost savings from reduced maintenance requirements are expected to be realized over a longer period time than the energy savings and have, therefore, have been less easily quantifiable in the early phases of adoption. For this reason, there is limited information on LED impacts on the maintenance of the streetlight conversion projects analyzed, as seen in Table 2.

Table 2: Expected and observed impact on maintenance requirements of LED-converted streetlighting

Jurisdiction	Date of First Installations	Fixture related Annual Maintenance Reductions
City of Barrie, CA	2015	\$280,000 or 77% expected
City of Edmonton, CA	2011	\$50,000 per 1,000 luminaires
City of Hamilton, CA	2015	\$65,000 for 10,000 luminaires
City of Las Vegas, US	2011	\$400,000-600,000 expected based the performance of the first installations
City of Los Angeles, US	2013	Approximately \$2.5 million
City of Mississauga, CA	2011	50%
Manitoba Hydro, CA	2014	Not quantified this early on but field staff have commented they are doing less troubleshooting of lights than before and outage calls are less frequent
New Brunswick Power, CA	2012	65% (which has already exceeded the 5-year target) and a failure rate to date of almost a negligible 0.2%.

Although it typically takes a few years to verify the impacts of LED conversions on maintenance costs, Table 2 shows there is the potential for significant savings, not only through the extended service life but also from extremely low failure rates. As with the energy savings of the eight analyzed projects, there has been no report of maintenance savings not meeting initial expectations.

Because the cost savings from energy and maintenance reductions have been met or exceeded in the LED conversions presented above, the project business cases have also been met. In some cases, conversions are achieving savings faster and greater than expected. For example, the City of Hamilton’s estimated payback for its 10,000-luminaire conversion was 3 years, but after installation, the actual payback has been 1.25 years. These cost benefits can come from early savings of installations ahead of schedule, decreases in luminaire costs or improvements in luminaire specifications throughout the project.

### 3.3 ENVIRONMENTAL BENEFITS

Data on resulting LED benefits that do not provide direct cost savings is less common, often because it is more difficult to quantify and sometimes less relevant to project managers. If carbon-based fuels are used to power streetlights, the impact on GHG emissions should be evaluated. The expected carbon emission reductions can be calculated based on resulting energy reductions and how much carbon is emitted from the electricity generated. Table 3 below presents expected reductions of select LED streetlight installations from North America and the United Kingdom.

Table 3: Expected carbon reductions from select LED streetlight installations

Jurisdiction	No. of LED Streetlights (in carbon calculation)	Expected Reduction in Carbon Emissions
City of Edmonton	30,000	5,500 tonnes annually
City of Hamilton, CA	10,000	690 tonnes annually
City of Los Angeles, US	140,000	47,000 tonnes annually
New Brunswick Power, CA	72,000	324,000 tonnes over 20 years
Liverpool City, UK	12,000	1,500 tonnes saved over the first two years of installation <sup>28</sup>
Surrey County, UK	90,000	60,000 tonnes across 25 years <sup>29</sup>

By reducing emissions, LED streetlights indirectly improve air quality for areas around coal burning power plants. The expected reduction in carbon emissions per LED luminaire varies between installations due to the differences in energy generation. For example, Manitoba Hydro is not expecting any direct reductions in emissions because it uses almost exclusively hydroelectric power, however the additional benefits of LEDs, both economic and non-economic, supported a strong enough business case for converting all of the utility’s 150,000 streetlights to LED.

### 3.4 QUALITY OF SERVICE

In addition, to reducing emissions, LED luminaires are expected to produce better quality light that improves visibility and therefore public safety and security. Although crime rates can be compared pre- and post-installation, it can be challenging to isolate LEDs as the sole variable, and is especially difficult to measure in the early phases of implementation. Impacts on visibility and safety are more commonly evaluated based on public surveys and responses collected during the pilot phase prior to full-scale implementation. Published results of surveys conducted by various organizations are summarized in Table 4 below.

<sup>28</sup> <https://liverpool.gov.uk/News/NewsItem/14759/14623/More-LED-street-lights-planned>

<sup>29</sup> <https://www.surreycc.gov.uk/roads-and-transport/road-maintenance-and-cleaning/street-lights-traffic-signals-and-signs/street-lights/street-lighting-replacement-programme>

Table 4: Summaries of survey results from public engagement in three LED pilot projects

Organization	Location: Year	Survey Summary
San Francisco Water Power Sewer <sup>30</sup>	San Francisco, US: 2014	Online survey of 71 residents and live demonstration to 21 residents obtained feedback on LED luminaires and adaptive controls. The majority of respondents agreed: <ul style="list-style-type: none"> <li>• The lighting is safe for both pedestrians and drivers;</li> <li>• There is not too much light on the street;</li> <li>• The light sources are not glaring;</li> <li>• The light is not uneven; and</li> <li>• The overall quality and appearance of LED lighting is an improvement.</li> </ul>
LightSavers with The Climate Group <sup>31</sup>	Global LED Trials (Toronto, Sydney, Kolkata): 2011	Pedestrians and drivers were surveyed in each city on their perception of the installed LED streetlights. Fifty percent or more of respondents in all cities reported an improvement in visibility and that LED lighting increased their feeling of safety.
Transit for London <sup>32</sup>	London, UK: 2011	400 face-to-face interviews were conducted with residents and drivers affected by LED streetlights in two trial areas of the city. Ten percent of respondents noticed the luminaires had been changed. Of those who had, the majority reported the lighting as ‘good’ or ‘excellent’. The majority of all respondents supported a full-scale rollout of LEDs in the future.

Canadian LED streetlight projects that have not conducted direct surveys on public perception have received comments from users post-installation, including, City of Edmonton, City of Barrie, City of Hamilton, City of Mississauga and Manitoba Hydro. As is reported to LightSavers, much of this feedback has been positive. Anecdotally, one of the concerns commonly heard from residents is caused by the reduced light trespass. Due to the directional nature of LED lighting, there is less light spillage on residential property leading some residents to believe there is insufficient illumination. However, a municipality can explain to residents that the city is only responsible for lighting roadways and sidewalks. Moreover, in many cases, residents support the transition to LED based solely on the expected energy savings, reduced costs and improved air quality from less reliance on carbon-based fuels.

<sup>30</sup> <http://www.sfwater.org/modules/showdocument.aspx?documentid=5630>

<sup>31</sup> <http://static1.squarespace.com/static/546bbd2ae4b077803c592197/t/552ea432e4b0e4e51050bceb/1429120050403/Meta-analysis.pdf>

<sup>32</sup> <http://content.tfl.gov.uk/LED-street-lighting-trial-one-page-summary.pdf>

## 4. LESSONS LEARNED

Based on realized results and public response to full-scale LED streetlight installations, we categorize common lessons learned as follows:

### 4.1 STREETLIGHT INVENTORY

For jurisdictions looking to make the switch to LEDs, it is important to first review the existing streetlight inventory. In many cases, the inventory has not been maintained since the initial streetlight design and installation, and few have been transferred to a digital record. Developing a detailed digital inventory prior to installation has shown to significantly improve ease and efficiency of project completion. Both New Brunswick Power and City of Hamilton created a streetlight database using GIS and have reported resulting benefits for budgets and schedules. According to Courtney Strong Inc., studies show that developing an ArcGIS inventory can result in 17% project savings<sup>33</sup>.

Hamilton engaged a third party GIS software company to help develop a GIS platform to use as a common database with all the streetlights as point features storing light-specific information. The database is used by design consultants, field consultants and city staff. Having all stakeholders working in a shared platform enabled the City to effectively monitor and manage the LED installation, leading to a project ahead of schedule and under budget.<sup>34</sup>

In-house preparedness is also improved by conducting yearlong pilots of pre-qualified LED luminaires to determine which product excels in performance, aesthetics and public response. Pilot installations minimize risk of failure, support the business case and give residents the opportunity to provide feedback prior to full scale-up.

More information on building the business case, financing, project design, procurement and installation and maintenance and commissioning is available in *LED Streetlight Scale-up: A LightSavers Guide*<sup>35</sup>.

### 4.2 LIGHTING DESIGN

Planning an LED streetlight conversion presents the opportunity for a lighting redesign. Early installations that directly retrofitted incumbent fixtures with LED luminaires based on matching light output often resulted in missed opportunities and some areas being over lit. Before designing a streetlighting system, a municipality should identify the actual intentions of illumination regarding how much light is needed and where. In this way, excessive illuminance and any roadway lighting redundancies installed since initial implementation can be eliminated, ensuring maximum energy savings are achieved with optimal visibility. Having a comprehensive inventory, allows the system to be analyzed as a whole based on actual needs.

The City of Seattle began retrofitting its HPS streetlights to LED in 2011. The City decided that to meet national standards it had to replace the incumbent lamps lumen-for-lumen with LED luminaires. However, the IES has explained that a conversion project should consider the total system and include photometric calculations to evaluate how the light is distributed by the new luminaires. Typically, LEDs of the same light output as HPS are effectively brighter because there is minimal loss to backglow and dispersion. Since the first installations, Seattle has had to, in some cases, reduce the output or add glare shields in response to public concerns. Despite this, the City maintains complaints from residents in 2012 were for less than 2% of the installed 31,000 LEDs.<sup>36</sup>

### 4.3 VISIBILITY AND GLARE

<sup>33</sup> <http://courtneystrong.com/2016/08/case-arcgis-audits-streetlight-inventory-now-can-save-later/>

<sup>34</sup> <http://www.lightsavers.ca/video/>

<sup>35</sup> <https://static1.squarespace.com/static/56cdde5262cd94f3e9c9cfd8e/t/57e03479197aea2b560ad2aa/1474311293803/5.LS.StreetlightGuide.16021.0.pdf>

<sup>36</sup> <http://crosscut.com/2013/03/streetlights-seattle-led/>



Many people believe that a brighter light increases visibility and therefore improves safety and security. In early LED conversions, lighting specifiers often favoured a brighter, whiter light without significant research being available on the actual effects on nighttime visibility. Recent research is suggesting that greater illumination does not directly correlate with better visibility and that whiter light may increase discomfort and glare.

Research was conducted in four different American cities to evaluate the objective and subjective impacts of light source, colour temperature and lighting levels on visibility, glare and the public's perceived safety<sup>37</sup>. Major conclusions of this study include:

- 4100K LEDs excelled in performance and were preferred by the public in at least one of the city trials;
- At 25% light levels, visibility was not statistically different from at 100% levels and the public felt equally safe, however some respondents found reduced backlight at 25% left the sidewalks too dark;
- LED luminaires with a G2 glare rating under the BUG rating method, had less glare than the incumbent HPS lamps;
- Uniformity did not improve detection; and
- Dimming did not appear to change the contrast of objects and contrast is correlated to visibility.

The results of this study demonstrate the importance identifying specific objectives for an LED streetlight conversion and then conducting a comprehensive pilot of LEDs with varying specifications.

#### 4.4 PUBLIC ENGAGEMENT

Pilot projects used prior to full-scale implementation to determine the most effective LED luminaire for the respective jurisdiction and confirm the technology meets manufacturers' claims can also be used to obtain the public's opinion. Some municipalities have received complaints from residents about the brightness of new LED streetlights. This is not necessarily a failure of LEDs but likely due to insufficient planning to determine the appropriate lighting for different areas of a community<sup>38</sup>.

The City of Davis in North Carolina did not include public engagement as part of the LED pilot tests. Davis initially tested LED luminaires with correlated colour temperatures (CCT) of 4000K and 5700K LED, choosing 4000K for scale-up. When LED installations began, residents shared concerns that the new lights appeared too bright, produced too much glare and trespass and increased skyglow. Due to the public's response, Davis replaced 650 of the 4000K LEDs with 2700K LEDs and increased house-side shields to reduce glare, costing \$300,000. By engaging the public in the initial trials, Davis would have likely avoided this loss and would have had the opportunity to further educate residents on the benefits of LEDs including, improved visibility.

#### 4.5 ENERGY COSTS

One of the main drivers for jurisdictions to support a conversion to LED streetlights is the potential cost saving from a reduced electricity bill. If electricity rates increase post-implementation, the total cost-avoidance is greater but the net savings may be less than projected. Consequently, when seeking funding requests, the promised cost reductions should be protected from general electricity rate increases. There are several financing models for municipalities to achieve this, including:

- Work with the local utility to determine a fixed rate for the expected payback period;
- Energy performance contracting where the risk of ownership is transferred to private energy service companies (ESCOs);
- Public private partnerships (P3) where the municipality grants a long-term license to a private sector that assumes most of the financial and performance risks for the duration of the contract while the municipality maintains ownership of the streetlights; and others.

<sup>37</sup> <http://volt.org/wp-content/uploads/2014/09/Tale-of-Four-Cities-Nancy-Clanton.pdf>

<sup>38</sup> <http://courtnestrong.com/2016/08/case-arcgis-audits-streetlight-inventory-now-can-save-later/>

As discussed, more information of streetlight conversion financing and delivery models is available in *LED Streetlight Scale-up: A LightSavers Guide*<sup>39</sup>.

#### 4.6 LIGHTING CONTROLS

As previously discussed, coupling LED luminaires with networked intelligent controls presents additional opportunities for energy savings, maintenance reductions and connected community services. Based on pilot projects and existing installations in North America and globally, adaptive controls have shown to successfully provide the intended benefits. During early LED implementations, controls were less proven and had high capital costs and were not included in many streetlighting system upgrades. However, with the technology advancements, recent installations have shown municipalities are likely missing significant savings if controls are not installed along with LED streetlight conversions. Firstly, implementing controls with LEDs saves installation costs of adding controls at a separate time. Secondly, waiting to install controls, a municipality will miss opportunities for additional energy savings now.

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<sup>39</sup><https://static1.squarespace.com/static/56cdde5262cd94f3e9cffd8e/t/57e03479197aea2b560ad2aa/1474311293803/5.LS.StreetlightGuide.160210.pdf>

## 5. BREAKING DOWN MISCONCEPTIONS

One of the main benefits promised of LED technology is decreased impact on the environment from reduced skyglow and light trespass and improved light quality. A recent report by the American Medical Association (AMA) and corresponding media coverage has raised concerns about the impact of LED lighting on the environment and human health<sup>40</sup>. However, in response, the streetlighting industry, including service providers, manufacturers, utilities and public health institutes, has provided evidence that demonstrates impacts are minimal and outweighed by the benefits<sup>41, 42, 43</sup>.

### 5.1 LIGHT AT NIGHT

In June 2016, the AMA published a report discussing the potential risks of blue light at night. This report specifically addresses LED streetlighting due to the commonly cooler light colour it produces compared to most legacy lamps, as well as its point source nature. The AMA claims that these two features have the potential to disrupt the circadian rhythm of living beings (a cycle of physical, mental and behavioral changes across 24 hours mostly in response to light and dark) and increase glare and light pollution. However, the report's overall conclusion was that, with proper design and pilot testing, communities should switch to LED streetlighting to achieve energy savings and carbon emissions reductions. The report's discussions on glare and blue light of streetlighting are summarized below.

#### a) Glare

According to the National Lighting Product Information Program (NLPIP), glare is a subjective sensation caused by uncontrolled and excessive brightness that either disables or discomforts a person visually. Disability glare occurs when an intense light source reduces visibility, whereas discomfort glare is experienced as an annoyance or pain induced by excessively bright sources.<sup>44</sup>

Based on its literature review, the AMA suggests that LED streetlighting has the potential to cause increased disability and discomfort glare through its point source nature and content of blue light. Point light sources are perceived harsher than extended light sources and may increase glare if not properly managed. Blue light has also been shown to be positively correlated with ratings of discomfort glare<sup>45</sup>. However, the AMA further deduces that through proper design and shielding, glare can be mitigated by ensuring there is no light output above 80 degrees from the horizontal and the CCT is 3000K or below. Light emissions are characterized by the colour temperature where the higher the CCT value the cooler the light and, typically, the greater the blue light content. Therefore, the AMA concludes, a 3000K light source will cause less glare than a 4000K.<sup>46</sup>

#### b) Blue light

Human's natural circadian rhythm includes a transition to nighttime physiology as the sun sets. This physiology includes melatonin secretion, temperature decrease and reduced hunger, leading to increased sleepiness. Studies have shown that exposure to short wavelength (blue) electric light during this period disrupts the circadian rhythm and delays the physiology transition. The AMA report suggests that products of

<sup>40</sup> <https://www.ama-assn.org/sites/default/files/media-browser/public/about-ama/councils/Council%20Reports/council-on-science-public-health/a16-csaph2.pdf>

<sup>41</sup> <http://www.dmdeng.com/wp-content/uploads/2016/06/Lighting-and-Health-Memo.pdf>

<sup>42</sup> <http://www.ledroadwaylighting.com/en/response-to-the-american-medical-association-statement-on-high-intensity-street-lighting.html>

<sup>43</sup> [https://publications.santemontreal.qc.ca/uploads/tx\\_asssmpublications/978-2-550-77376-4.pdf](https://publications.santemontreal.qc.ca/uploads/tx_asssmpublications/978-2-550-77376-4.pdf)

<sup>44</sup> <http://www.lrc.rpi.edu/programs/nlpip/lightinganswers/lightpollution/glare.asp>

<sup>45</sup> <https://deepblue.lib.umich.edu/bitstream/handle/2027.42/57444/98625.pdf?sequence=1>

<sup>46</sup> <https://www.ama-assn.org/sites/default/files/media-browser/public/about-ama/councils/Council%20Reports/council-on-science-public-health/a16-csaph2.pdf>

4000K CCT have significantly higher short wavelength emissions than those of 3000K CCT and therefore, greater potential to disrupt the circadian rhythm. This applies to any type light source, however, because they are commonly manufactured with a 4000K CCT, the AMA specifically discusses LED streetlight luminaires. To minimize the impact of nighttime lighting on human and animal circadian rhythms, the report recommends that LED streetlights are specified at 3000K or lower, outfitted with adaptive controls and dimmed during off-peak times.<sup>47</sup>

The report concludes that the AMA supports LED streetlighting with the recommendations of low blue light emissions, proper shielding and dimming schedules.

## 5.2 HUMAN HEALTH

Although not indicated by the AMA report, there has been some misinformation throughout the public that the AMA believes LED streetlighting is inherently harmful to human health and the environment. For this reason, there has been significant review and response to the report's discussion.

The U.S. Department of Energy (DOE) provided a response to the AMA report agreeing that, as with any type of roadway lighting, objectives are to illuminate only the areas required; confirm the spectral content promotes visibility and safety while supporting the health of living beings; and minimize glare for all users. However, the DOE concludes that LEDs have advantages over other technologies for achieving these desired outcomes, including:

- Suitability for controls and dimming that can match illumination to actual needs at any time;
- Directionality of light output that improves the pattern and evenness of light on the ground and minimizes light spillage on wildlife;
- Increased perceived brightness, enabling LED luminaires to often meet lighting requirements with half the total lumens of an HPS lamp; and
- Ability to tailor the spectral content, meaning LEDs are available in a range of CCT values.

Although the DOE acknowledges there is the potential that low CCTs will reduce nonvisual impacts of outdoor lighting, there is a greater potential for reduced effectiveness of lighting regarding visibility and security.<sup>48</sup>

Other responses to the AMA report echo the concern of providing the singular solution of lowering CCT values to 3000K, without evidence based research specifically demonstrating detrimental effects of streetlights with higher CCTs. As outlined by the National Electrical Manufacturers Association (NEMA), lighting design requires evaluation of many criteria, CCT being one. Furthermore, lighting requirements of outdoor systems, including spectral content, will vary based on application and local conditions. Impacts on visibility, energy savings, capital costs, safety and security and the environment cannot be optimized with a single solution for all systems.<sup>49</sup>

The Lighting Research Center (LRC) at Rensselaer Polytechnic Institute has further concluded that CCT cannot appropriately characterize the potential human health impacts of a light because of the CCT value does not adequately describe light exposure in terms of the amount, duration and timing.<sup>50</sup>

DMD & Associates Ltd. prepared a memo summarizing previous research conducted on the relationship between streetlight CCT and human health and concluded CCT alone does not indicate health impacts. The memo also

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<sup>47</sup> <https://www.ama-assn.org/sites/default/files/media-browser/public/about-ama/councils/Council%20Reports/council-on-science-public-health/a16-csaph2.pdf>

<sup>48</sup> [https://energy.gov/sites/prod/files/2016/06/f32/postings\\_06-21-16.pdf](https://energy.gov/sites/prod/files/2016/06/f32/postings_06-21-16.pdf)

<sup>49</sup> <http://www.nema.org/news/Pages/NEMA-Comments-on-American-Medical-Association-Community-Guidance-Advocating-and-Support-for-Light-Pollution-Control-Efforts.aspx>

<sup>50</sup> <http://www.lrc.rpi.edu/resources/newsroom/AMA.pdf>

presents data that shows a person's exposure to blue is significantly greater from devices and lighting in a home or workplace than from roadway lighting. Finally, DMD compared the spectral power distribution of 3000K and 4000K LED streetlights and found 3000K only reduced the luminaire's potential impact on the circadian rhythm by 6 percent, while likely requiring increased light levels for adequate object detection.<sup>51</sup>

Another study by the National Institute of Public Health Quebec on streetlight CCT, conducted at a similar time but independent of the AMA report, presented the following findings:

- The current state of knowledge does not demonstrate a causal relationship between exposure to light at night and the occurrence of adverse health effects;
- The exposure to blue light emitted by 4000K LED luminaires is at least three times lower than the exposure from lights found in homes;
- Blue light from 4000K LED that spills in homes is minimal; and
- The design and installation of a new streetlighting system must follow best practices to ensure lighting is safe.<sup>52</sup>

The key lesson from this work is the importance of designing a streetlight system to meet actual needs, regardless of the light source. For example, a municipality may choose different luminaire specifications for residential and arterial roads.

### 5.3 IMPLICATIONS FOR END-USERS

The recently produced research on the human impacts of light at night generally agrees that, with proper design, incumbent HID lamps should be replaced, at full-scale, with LED technology to achieve the environmental, social and cost saving benefits. As with any light source: potential glare from the luminaire should be mitigated using proper shielding and fixture type; the public should be engaged throughout the conversion process; and CCT should be determined based on roadway classification, for example, considering luminaires with warmer CCTs in residential and natural areas.

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<sup>51</sup> <http://www.dmdeng.com/ama-medical-health-warning-led-street-lights/lighting-and-health-memo/>

<sup>52</sup> [https://publications.santemontreal.qc.ca/uploads/tx\\_assssmpublications/978-2-550-77376-4.pdf](https://publications.santemontreal.qc.ca/uploads/tx_assssmpublications/978-2-550-77376-4.pdf)

## 6. CONCLUSION

Based on the case examples reviewed throughout this report, LED streetlight technology has demonstrated to meet or exceed the expected benefits and are saving millions of dollars for municipalities across the world. Some of the first adopters helped resolve early technological challenges and show the potential opportunities of converting. Many existing installations are now observing 50% or more in energy savings with failure rates below 1 percent adding to the significant maintenance savings. These cost-avoidances coupled with product cost lower than some HID lamps, helps build a robust business case for installing LEDs now. Concerns with CCT and blue light at night have largely been addressed by the industry as negligible and outweighed by the benefits. Furthermore, LED luminaires are available in a range of CCTs that now have similar energy savings. Most importantly, when considering a switch to LEDs, pilot testing of multiple products is necessary for determining the most effective solution for the local conditions and assessing public response. Early adopters have provided evidence-based reasoning for LED streetlight installations by establishing that lighting standards can be met while intended benefits are achieved and additional opportunities are presented for newer technologies like networked intelligent controls.